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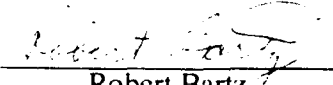
PROGRESS REPORT
TO
OFFICE OF NAVAL RESEARCH

FOR CONTRACT NO: N00014-90-C-0123

TITLE: Development of an Expendable Particle Sensor

ITEM NO: 0001AE

DATE: 3 September 92

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PROGRESS REPORT:

Development of an Expendable Particle Sensor

Sea Tech Inc.

Contract No. N00014-90-C-0123

Item No. 0001AE

INTRODUCTION:

This report addresses progress on the Phase II Development of the Expendable Particle Sensor (EPS) over the time period of April through July 1992. Significant technical progress has been made during this time related to the study and measurement of the XOTD transmission line characteristics. The results of the study and measurements allowed Sea Tech to design the telemetry system line receiver to interface with the Sparton transmission line. The new telemetry system was then tested in both the laboratory and the field with excellent results.

Telemetry System Design and Evaluation

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Transmission Line:

Determining the characteristics of the two wire transmission line for both air and water consumed a significant amount of time during this period. An understanding of transmission line characteristics is essential if the transmission line receiver is to be designed with optimum performance.

The resistance, inductance and capacitance are the fundamental electrical characteristics of the transmission line. The resistance of the wire is given by the manufacturer and is 2.8 Ω per meter. The transmission line inductance has no effect because a differential source is used to drive the transmission line, and therefore it is ignored. The capacitance of the transmission wire is not given by the manufacturer, so it was necessary to calculate and measure the bifilar wire capacitance for both air and water environments. The results of this work are included in Appendix A. These calculations agree very well with the measured values for the actual transmission line in both air, salt water and fresh water. The calculations and measurements allowed Sea Tech to develop a computer model that would accurately predict telemetry system frequency response with the transmission line in air.

The spectral response of the wire was measured with a spectrum analyzer in both air and water in Nanoose Bay, British Columbia. The results of these measurements, shown in Figures 2 and 4, show that the computer model predicts the losses through the transmission line very accurately.

The equivalent circuit for the transmission line that was used for the computer model of the transmission line in air is shown in Figure 1. The model is based on the manufacturer specified resistance of the wire and the capacitance of the wire measured in the laboratory. The computer-generated Bode plot for this circuit is shown in Figure 2 and shows that the maximum attenuation is 6 db at 1500 Hz, the upper frequency range planned for the telemetry system. The losses over 2800 feet of the wire measured on a spectrum analyzer are also plotted in Figure 2. The difference between calculated and measured attenuation values for the transmission wire is within approximately 3 db over the entire frequency range of interest, 500 to 1500 Hz.

The equivalent circuit for the transmission line in that was used for the computer model of the transmission line in water is shown in Figure 3. This model is based on the manufacturer specified resistance of the wire and the capacitance of the wire measured in the laboratory (measured capacitance was the same in fresh water and salt water). The computer generated spectral response of this circuit is shown in Figure 4. The losses over 2800 feet of unspooled, submerged wire was measured with the spectrum analyzer. The results are plotted in Figure 4: even better agreement between measured and computer-generated values was achieved within the frequency range of interest.

Telemetry System Performance:

Data was transmitted through the wire in Nanoose Bay as the wire was unspooled into the water, using a modified XOTD sensor/transmitter board and receiver card containing the newly-designed line receiver. The modified sensor/transmitter board had an input to channel 1 equal to 66.54% of supply voltage and channel two equal to 33.26% of supply voltage. The field test data was obtained over a several period in a typical shipboard environment. As the data in Figure 5 shows, test conditions ranged from all wire in air to all wire in water. The field test data in Figure 5 shows that telemetry system accuracy is approximately 0.1% and system noise is approximately 0.05%. This accuracy and noise level for the telemetry system was the same as that measured in a laboratory environment.

Since this field test represented the first real world test for this instrument, significant effort was made to determine if any interference problems could be detected. System output was evaluated for the effects of background noise and or radio frequency interference in a normal sea going environment: people talking on the VHF radio, radar going and depth sounder running. These tests were done in a qualitative way; no actual measurements were made of interfering signals from the radio, radar or depth sounder while data was being collected from the XOTD telemetry system. As the collected data in Figures 5 shows, there was no problem with interference so it can be assumed that the XOTD telemetry system signal to noise ratio is adequate and that the system will function properly in a normal shipboard environment. To further test interference after data collection was complete, a VHF transceiver with 3 watt output was placed within 6" of the deck wire spool and no increase in system noise was observed. The system noise did increase however when the VHF transmitter antenna was located directly on the XOTD wire spool and in line with the wire spool axis. No interference was noticed when the antenna was perpendicular to the wire spool axis. These results are quite significant because it demonstrates that this system will function properly in a radio frequency environment with high strength interfering signals. The immunity to radio frequency interference is not by accident; the telemetry system line receiver has been designed to receive signals using a differential amplifier which has very high common mode rejection and RF filtering has been incorporated as well. In conclusion this telemetry system design appears to work very well at sea in a shipboard environment.

Figure 1 AXOTD & XOTD Wire Model, upper and lower spool in air.

The circuit model is based on the measured value of 10 meters of the two conductor 39 AWG transmission line to be used for the AXOTD &XOTD.

Where R = 2.8 Ω/meter and C = 0.1 nF/meter in Air

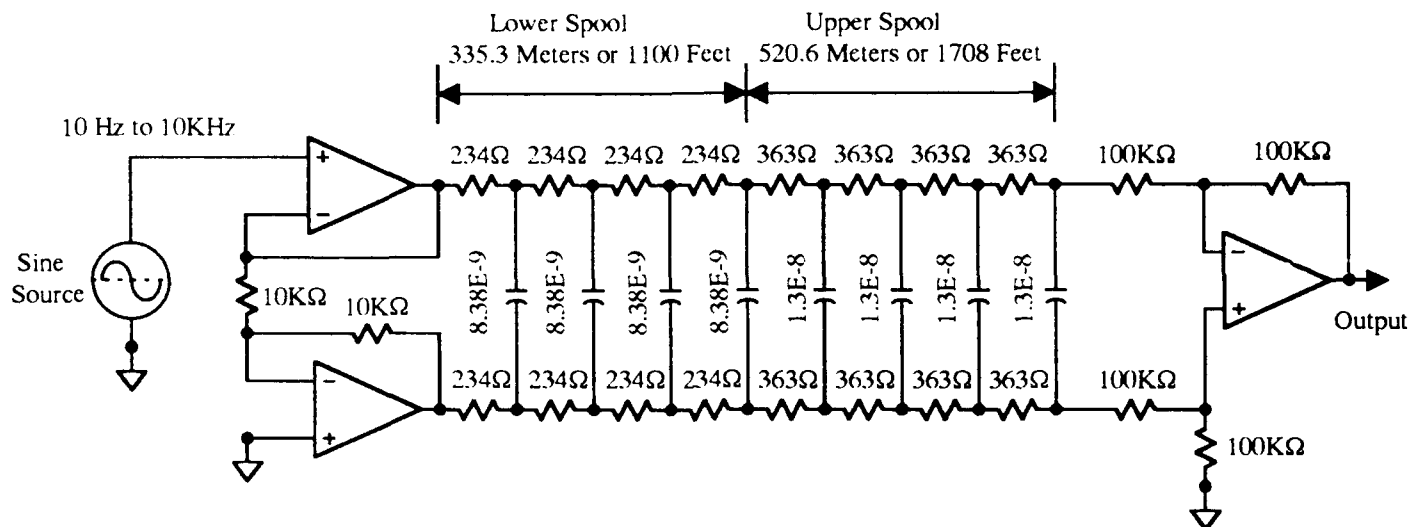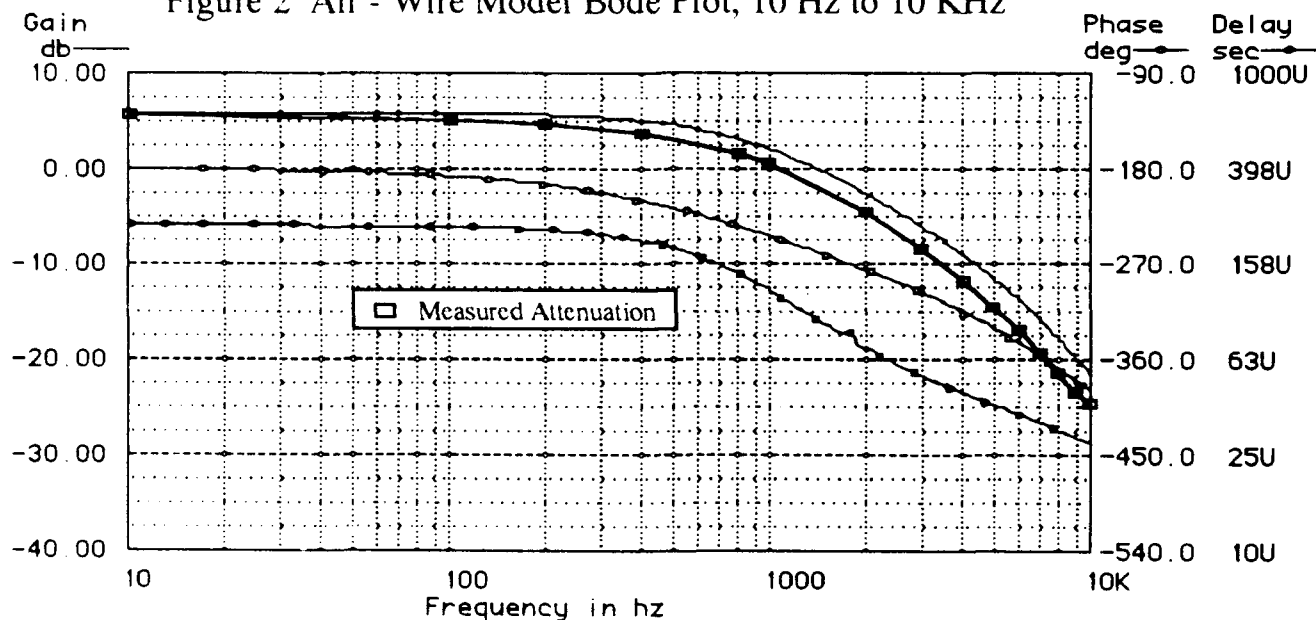# Figure 2 Air - Wire Model Bode Plot, 10 Hz to 10 KHz


```
Frequency   =  100.00000E+02    hz          Gain        =  -21.587 db
Phase angle = -390.32041E+00    degrees     Group delay =  277.64495E-07 sec
Gain slope  = -119.37479E-01    db/octave   Peak gain   =    5.806 db/F =  1.000E+01
Frequency delta =  128.00000E+00             Analysis point number 161
```

Figure 3 AXOTD & XOTD Wire Model. all wire spooled out in salt water.

The circuit model is based on the measured value of 10 meters of the two conductor, 39 AWG transmission line to be used for the AXOTD & XOTD.

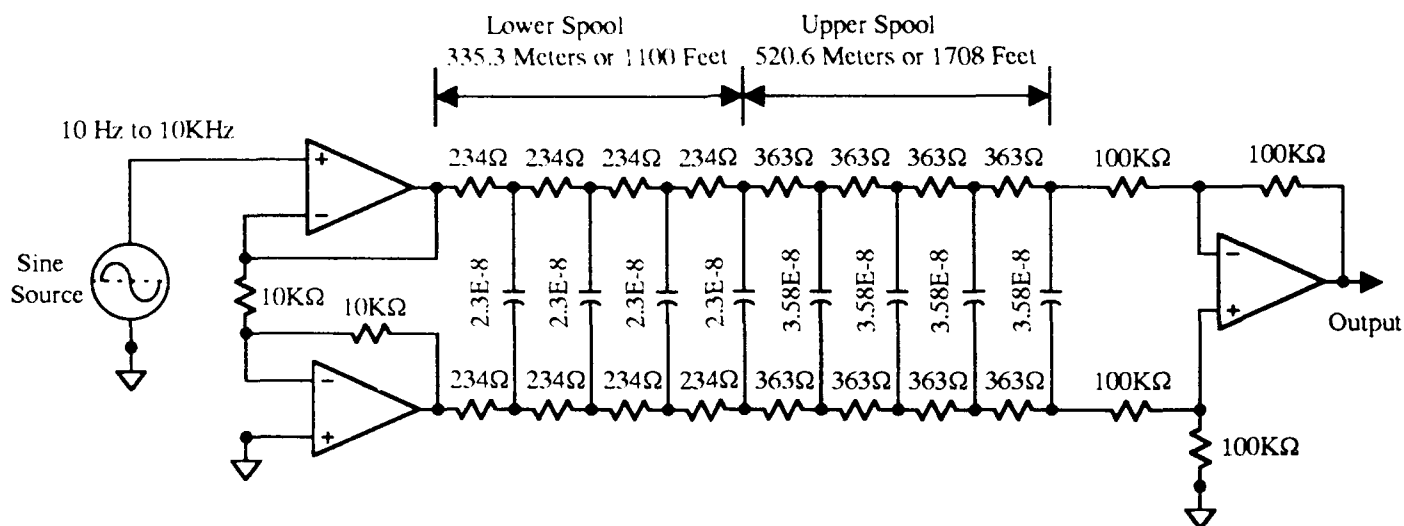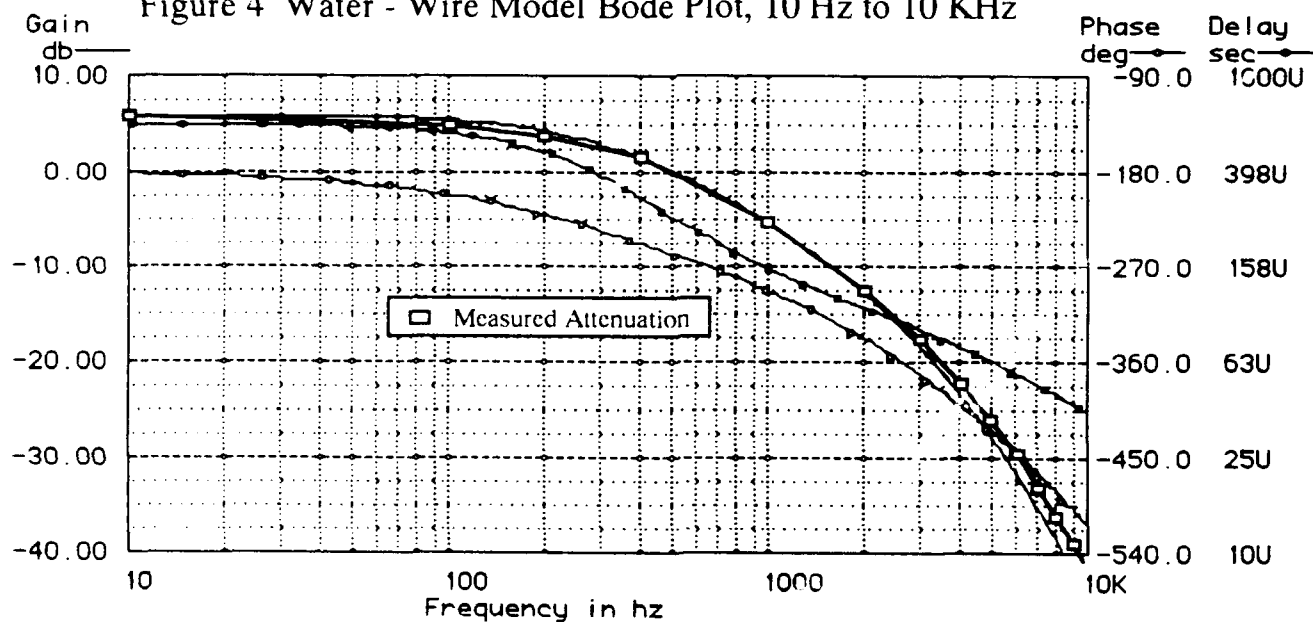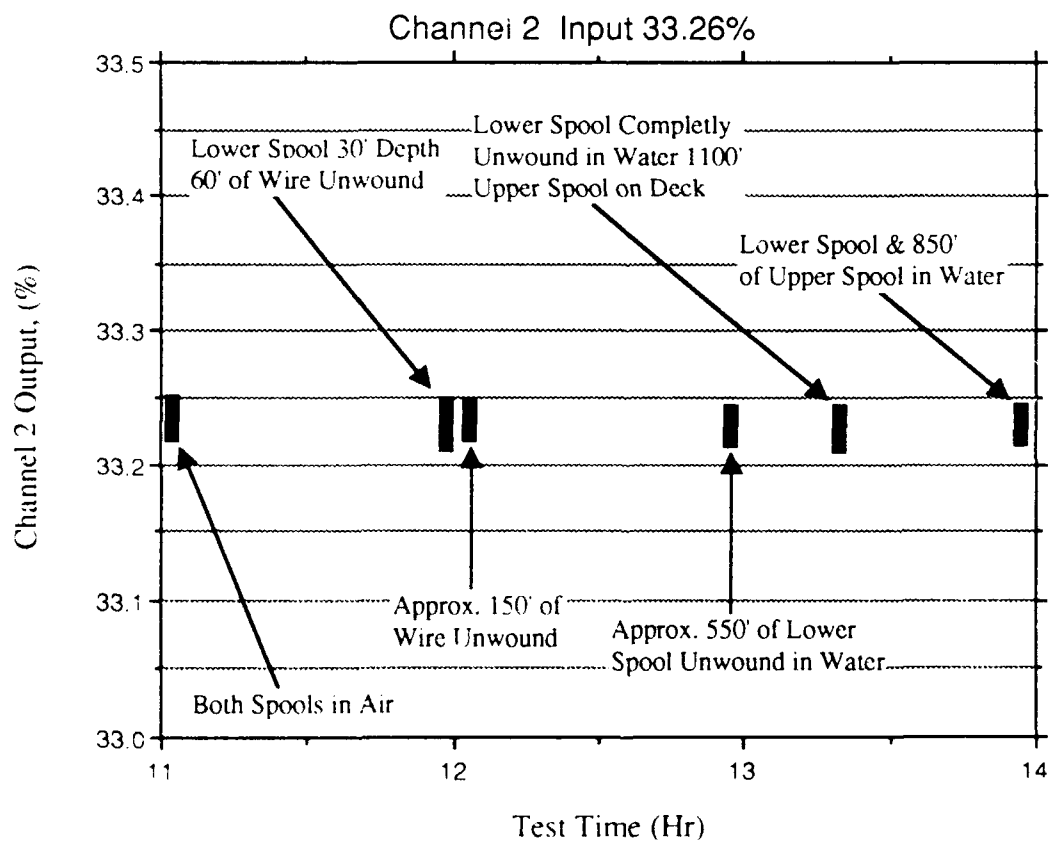Where R = 2.8 Ω/meter and C = 0.275 nF/meter in Salt Water

Figure 4 Water - Wire Model Bode Plot, 10 Hz to 10 KHz


```
Frequency    =  100.00000E+02   hz        Gain        =  -44.913 db
Phase angle  = -512.23477E+00   degrees   Group delay =  389.73472E-07 sec
Gain slope   = -207.54325E-01   db/octave Peak gain   =    5.802 db/F =  1.000E+01
Frequency delta =  128.00000E+00           Analysis point number 252
```

Figure 5 Telemetry System Field Performance

Channel 1 Input 66.54%

Lower Spool 30' Depth
60' of Wire Unwound

Lower Spool Completly
Unwound in Water 1100'
Upper Spool on Deck

Lower Spool & 850'
of Upper Spool in Water

Approx. 150' of
Wire Unwound

Approx. 550' of Lower
Spool Unwound in Water

Both Spools in Air

Channel 1 Output, (%)

Test Time (Hr)

Channel 2 Input 33.26%

Lower Spool 30' Depth
60' of Wire Unwound

Lower Spool Completly
Unwound in Water 1100'
Upper Spool on Deck

Lower Spool & 850'
of Upper Spool in Water

Approx. 150' of
Wire Unwound

Approx. 550' of Lower
Spool Unwound in Water

Both Spools in Air

Channel 2 Output, (%)

Test Time (Hr)

Appendix A

Characteristics of the AXOTD & XOTD TRANSMISSION LINE

Resistance

The resistance of the 39 AWG bifilar magnet wire used for the AXOTD and XOTD is specified to be 850Ω per 1000 feet +/- 100Ω at 20°C. This converts to 2.8Ω +/- 12% per meter.

Inductance

The AXOTD and XOTD wire spool inductance has no effect on data transmission because the two wire transmission line is driven by a differential source.

Capacitance

The capacitance per unit length between the conductors of the two-wire transmission line is given by:

$$C = \pi e / (\cosh^{-1} (D/2a))$$

where e is the permittivity of the cable insulation, D is the distance between the centers of the conductors, and a is the radius of each conductor. A cross section of the 39 AWG bifilar transmission line used for the AXOTD and XOTD is shown below.
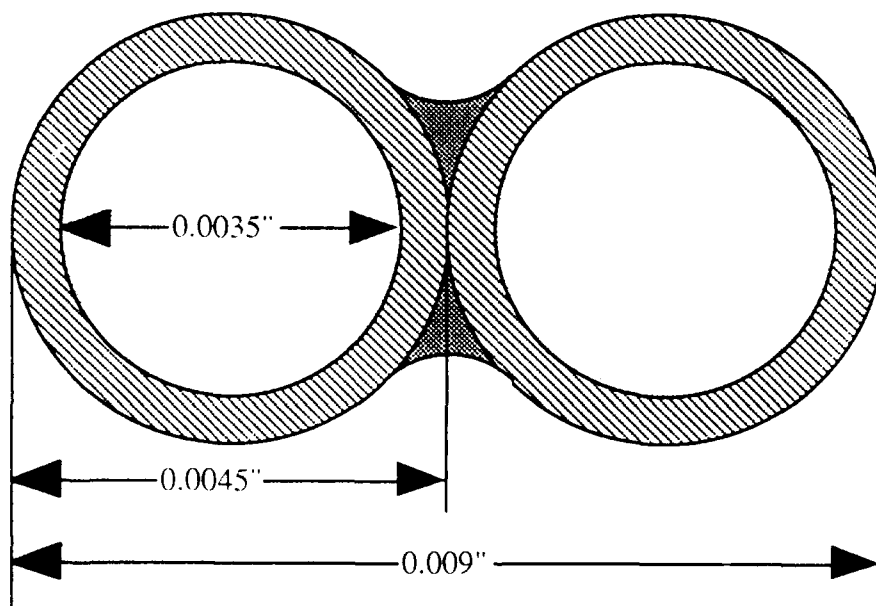
Cross Section of theTwo Wire AXOTD & XOTD Transmission Line

The dimensions of the 39 AWG bifilar wire are, D=0.0045" and a=0.00175". The insulation is assumed to have a dielectric constant of 2.1, which means e is $2.1 * (1/36\pi) * 10^{-9}$ F/m or 1.86×10^{-11} F/m. Thus, our theoretical value of C for the 39 AWG bifilar wire in air is approximately 0.08 nF/m. The measured capacitance in air of the 39 AWG bifilar wire is 0.075 nF/m.

The capacitance of the unwound wire in salt water can be calculated if we determine the capacitance between each conductor and the surrounding salt water. The total capacitance per unit length between the wires can be modeled as shown in the schematic below.
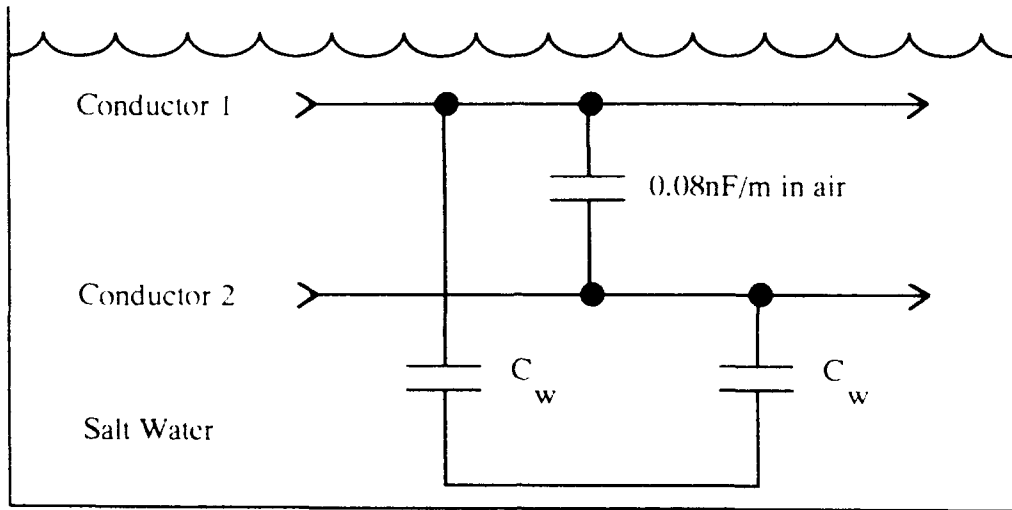
Total Capacitance per Unit Length for the 39 AWG Bifilar Wire in Salt Water

Thus, the total capacitance per unit length of wire in salt water is 1/2 the capacitance per unit length between each conductor and the surrounding salt water, plus the capacitance per unit length between the conductors in air, which we already calculated as 0.08nF/m.

To calculate the capacitance between each conductor and sea water, we assume that all significant capacitance is due to the portion of the conductor separated from the sea water by a small distance, which is the case for approximately 280 degrees around the conductor, as shown below.
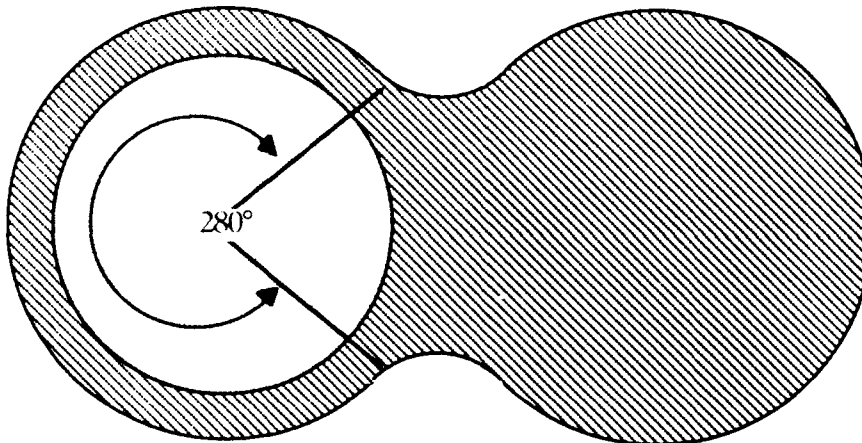
Area of Significant Capacitance between
Conductor and Surrounding Salt Water

We then model this portion of the cable as a parallel plate capacitor. Capacitance per unit length for a parallel capacitor is given by:

$$C = ew/D$$

where e is the dielectric constant of the material between the plates, w is the width of each plate, and D is the distance between the plates.

In this case, the length of the 280 degree arc on the outside of the conductor is $\pi(0.0035")(280)/360 = 0.0086"$ while the length of the 280 degree arc on the outside of the insulation is $\pi(0.0045")(280)/360 = 0.011"$. We assume that this is approximately equivalent to parallel plates with w=0.010". D=0.0005", and e=1.86x10^{-11} F/m, so C=0.37 nF/m between each conductor and salt water. The total capacitance between the two conductors is then 0.5*0.37+0.08 = 0.27 nF/m. This agrees closely with the measured capacitance of the 39 AWG bifilar wire in salt water, 0.275 nF/m.

For these calculations, we chose an arbitrary dielectric constant for the wire insulation. In reality, we do not know what this dielectric constant is. In addition, we have simplified the geometry for our models. Still, our calculated values are close to the values we measured for the 39 AWG bifilar wire in salt water.